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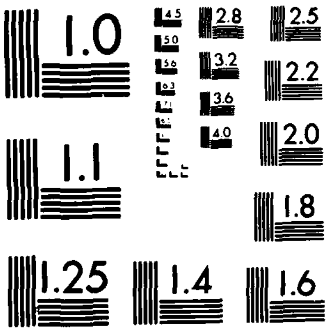

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This paper presents several three-dimensional feature extraction techniques for use on laser reange imagery. These include object-gound segmentation, projection image generation from range data, and 3-D physical edge detection. We emphasize extracting 3-D physical features of the object from 3-D range data without restricting ourselves in a sensor-centered range image format. The object-ground segmentation and projection image generation techniques extract global object features from range data, and are useful for object orientation Cont.

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THREE-DIMENSIONAL FEATURE EXTRACTION*

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ABSTRACT

This paper presents several three-dimensional feature extraction techniques for use on laser range imagery. These include object-ground segmentation, projection image generation from range data, and 3-D physical edge detection. We emphasize extracting 3-D physical features of the object from 3-D range data without restricting ourselves in a sensor-centered range image format. The object-ground segmentation and projection image generation techniques extract global object features from range data, and are useful for object orientation estimation and major structures identification. The 3-D physical edge detector directly calculates the physical angle of the object surface. It is not only useful for physical edge (convex, concave, occluding) detection, but also provides useful information for extracting planar and curved surfaces. END

INTRODUCTION

START Range images offer significant advantages over passive reflectance images because they preserve the 3-D information of the scene viewed from the sensor. Therefore, range data is becoming an increasingly important source of information for a variety of applications including 3-D target classification, autonomous vehicles, and robot vision. This research is part of an effort to develop a 3-D object recognition system for vehicle objects in air-to-ground laser range imagery. The full system includes image feature extraction, object modeling, model-driven prediction, and feature to model matching [1]. This paper reports on feature extraction techniques developed in this effort.

OBJECT-GROUND SEGMENTATION

Knowledge of the physical relationship between object and ground can aid the segmentation. An object is a connected 3-D blob with finite extent and is supported below by a ground plane that is locally flat. Furthermore, there are no data points below the ground plane. These properties allow us to select a threshold z_0 (along the z axis in world coordinates as in Figure 1) to separate those object points at least z_0 distance above the lowest ground point. The next step is to perform downward-continuation such that we can lower the threshold to extract more object points without including ground points. The connectivity property of the object and concave edge evidence are used for this purpose. Figure 2 is a noisy synthetic range image (64x64) of a vehicle above an uneven ground support. Long range distance shows up brighter in the image. The object segment extracted from the range image through downward-continuation is shown in Figure 3.

PROJECTION IMAGES GENERATION

The range image is recorded as a perspective view of the scene seen from the sensor position. The surface data obtained from range image through coordinate transformation removes this specific image format and permits effective manipulation of 3-D data. Projection image corresponds to the projection of the 3-D surface data onto a specified plane.

One of the most important pieces of information about the object in the scene is its orientation. This information is not directly available from the range image. However, we can estimate the object orientation easily from the ground projection image. Figure 4 is the projection of the object segment in Figure 3 onto the ground plane. This projection image provides the top view of the object that is not available from the sensor position and the orientation of the object can be obtained from the orientation of the most elongated bounding rectangle on those projection points.

Other important characteristic views can also be obtained from projections. For example, we can project the surface data to the plane defined by the orientation of the vehicle and the z-axis to obtain the side view of the object. Figure 5 is the side view projection image of the object segment in Figure 3. Much structural information not available from the sensor position shows up in this side view projection. For simple objects, the

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orientation and the characteristic side views may be sufficient for object recognition and manipulation.

3-D PHYSICAL EDGE DETECTION

Physical edges such as occluding, convex, and concave edges that are not distinguishable in the intensity image can be extracted from the range image directly. The occluding edges correspond to large range discontinuity caused by object occlusion and can be easily extracted. However, jump boundaries are regions subject to large measurement error due to the splitting of the scanning beam across occluding boundary. Here, we extract the occluding exterior boundary of an object by tracing the boundary of the extracted object segment. Since the connectivity analysis has been performed on the object segment, large error points are removed from the segment and we have more confidence on the 3-D information of the edges. Figure 6 is the exterior boundary obtained from the object segment in Figure 3.

The large range discontinuity is the result of occlusion or range shadow casting caused by z coordinate difference. Therefore, occluding edges can also be extracted from surface data according to z coordinate discontinuity and are more closely related to the physical properties of the object rather than the properties seen from the sensor. The importance of this direct physical relationship becomes more clear for convex and concave edges.

There are certain invariant properties of shapes that are in general independent of the sensor position. For example, three collinear points in 3-D space will be collinear in the 2-D projection images viewed from different positions. This invariant property of collinear relationship is a singular case of a more general invariant property about the convex and concave angles. That is, a convex angle in 3-D will always appears to be nonconcave in 2-D images, and similarly, a concave angle in 3-D will always be a nonconvex angle in 2-D images. Figure 7 shows the region of apparent angle on the image plane for determining 3-D convex and concave angle. The polarity information is qualitatively sufficient to distinguish between convex and concave edges [2], but it is not a quantitative measure that characterizes the physical properties of the object. Here, we calculate the physical angle of three surface data points along a specified direction. For example, let the surface data (x,y,z coordinates) of a range image at pixel (i,j) be a vector r(i,j). The distance from the sensor to the object point is |r(i,j)|. If the column direction is chosen, the vectors a(i,j) and b(i,j) are defined as a(i,j)=r(i-s,j)-r(i,j) and b(i,j)=r(i+s,j)-r(i,j); where s is the step size. The step size is chosen according to the resolution and the amount of noise in the range image. The angle between a(i,j) and b(i,j) can be determined from their inner product and cross product. Those points with concave angle (180 to 360 degrees) are candidates for concave edges, and the threshold selection for physical edge detection becomes an image-independent physical threshold selection (between 0 and 360 degrees). To avoid the singular case (edges along the column direction), we need to calculate the edge angle along the row direction. Figure 8 is the physical edge angle image along the column direction with step size equal to two. The edge angle is between 0 to 360 degrees and the intensity of the image is proportional to the edge angle. Bright edges are concave edges. After thinning, linking, and recursive line fitting processes similar to Nevatia-Babu edge detector [3], the concave edge segment and the boundary contour in Figure 6 are shown in Figure 9. These edge segments are useful to segment complex object into simpler subparts even for objects with self-occlusion.

The physical edge angle image also provides local surface orientation information [4]. Instead of thresholding convex or concave edges, we can merge locally connected points with physical angle close to 180 degrees to extract planar surface. A curved surface such as the cylinder on top of the vehicle platform will show as connected points with their edge angles cluster in a convex angle region. Thus our 3-D edge feature extraction algorithm is not only useful for physical edge detection, but also suitable for surface primitives extraction.

CONCLUSION

We presented several 3-D feature extraction techniques. These algorithms work on surface data instead of the range image, hence they are applicable to range data obtained from various 3-D sensing techniques such as stereo, light-stripe, and time-of-flight. We emphasize on extracting 3-D physical features of the object from coarse to fine by using 3-D range data without restricting ourselves in a sensor-centered range image format. These physical features are useful for 3-D object recognition and manipulation, and their physical properties strongly constrain the interpretation of the scene.

ACKNOWLEDGEMENTS

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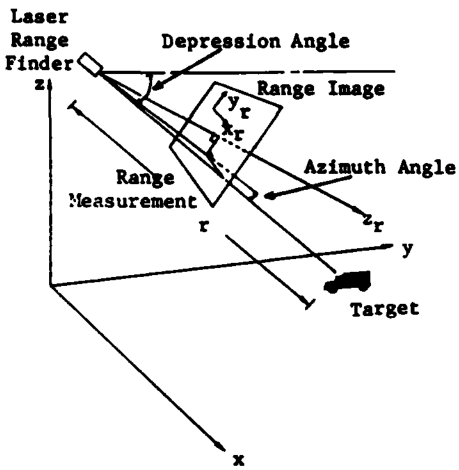

Figure 1 Coordinate Transformation Between a Sensor-Centered Coordinate System and the World Coordinate System

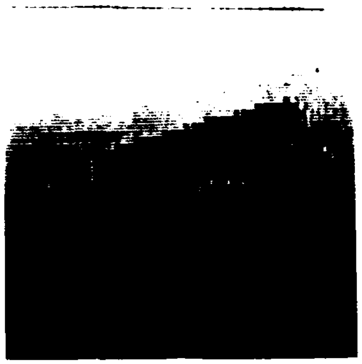

Figure 2 Range Image of a Vehicle Object

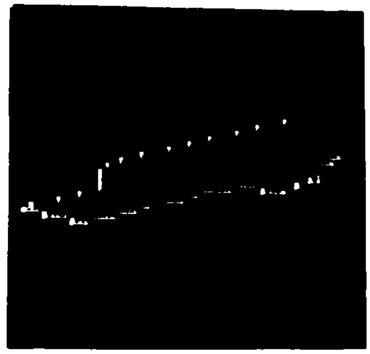

Figure 3 Extracted Object Segment

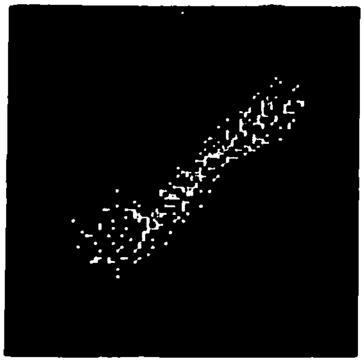

Figure 4 Ground Projection of Figure 3

Figure 5 Side-View Projection of Figure 3

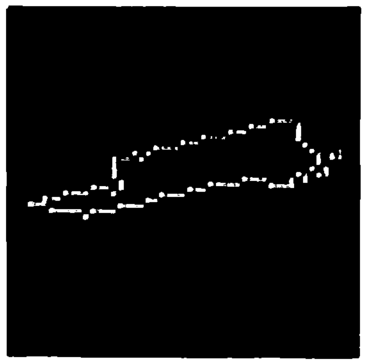

Figure 6 Exterior Boundary of Figure 3

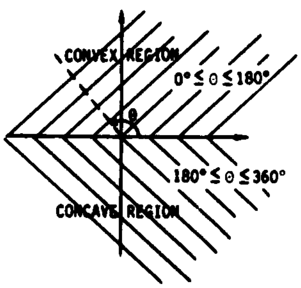

Figure 7 Region Diagram of Convex and Concave Angles

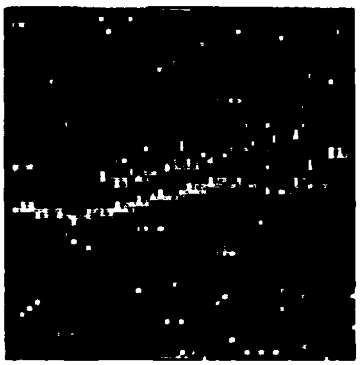

Figure 8 Physical Edge Angle Image of Figure 2

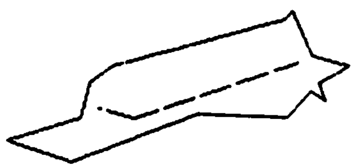

Figure 9 Linear Features of Occluding (solid-line) and Concave Edges (dashed-line)

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